MONITORING AND MODELING SUBGRADE SOIL MOISTURE FOR PAVEMENT DESIGN AND MAINTENANCE IN IDAHO

PHASE ONE: DEVELOPMENT OF SCOPE OF WORK

Final Report

Submitted to

Idaho Transportation Department
P. O. Box 7129
Boise, Idaho 83707-1129

by

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ITD Project No. RP 124, Agreement #96-48
NCATT, U of I Contract No. FM-K428

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CHAPTER ONE

INTRODUCTION

This report contains the results of the research conducted for Phase One of the project "Monitoring and Modeling Subgrade Moisture for Pavement Design and Maintenance in Idaho." The first chapter of the report presents a brief review of the background and long-term project objectives. The specific objectives of Phase One: Development of Scope of Work, which had to do mainly with identifying instrumentation and locations for long-term pavement and subgrade condition monitoring are described in detail. Chapter Two contains a review of the pavement and subgrade condition parameters selected for monitoring (temperature, moisture, and depth of frost), a brief description of available instrumentation and a summary of the costs of the devices recommended for the project. Chapter Three describes the location selected for the initial instrument installations. The final chapter of the report describes the subsequent phases of the project including the installation of the selected instrumentation, laboratory tests to characterize and classify the soils and pavement and the collection and evaluation of the subgrade and pavement condition data.

1.1 Background

Two recently completed research projects at the University of Idaho Department of Civil Engineering presented recommendations and guidelines for the use of non-destructive evaluation of pavement structures by falling weight deflectometer (FWD) (1.1)* and provided initial resilient modulus values for the range of pavement subgrade soils encountered in Idaho (1.2). Tentative adjustment factors to reflect seasonal and long-term variations in subgrade resilient modulus value occurring in response to post-construction changes in subgrade conditions were developed for the

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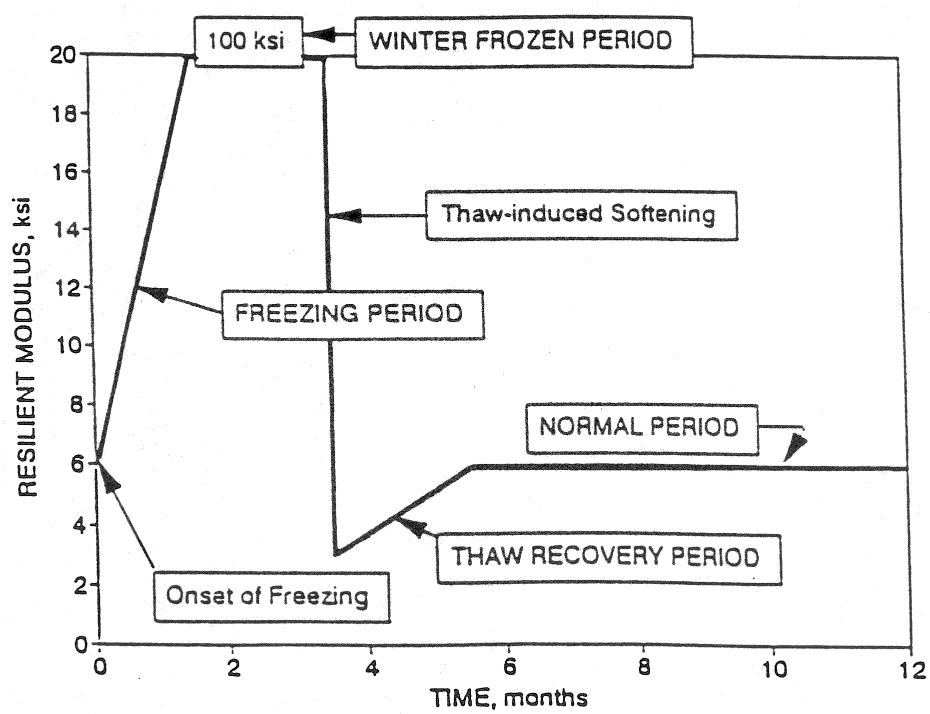
*Numbers in parenthesis refer to references listed in Appendix One soils and climate conditions of Idaho. The assessment of the temporal variations in pavement materials and subgrade soils is a key element in the movement toward the so-called mechanistic pavement design approaches currently being advocated by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) (1.3), and allow the annual variations in subgrade modulus, like those shown in Figure 1.1 to be included in the design of pavements and overlays.

Part of the mechanistic analysis is the evaluation of truck traffic loads which are generally determined by weigh-in-motion (WIM) scales at several locations in Idaho. The WIM scales utilize piezoelectric sensors permanently installed in the pavement structure. Calibration of the dynamic loads sensed by a WIM scale to known static loads helps account for the dynamics of the vehicles, pavement smoothness and pavement response to these loads. The WIM measurements do not account for the changes in the pavement structure that occur over time due to variations in subgrade support.

The tentative factors for adjusting subgrade support (resilient modulus) developed in the research referred to above were based exclusively on data and models derived in studies conducted outside the state of Idaho. Obviously, there exists a need to calibrate and refine the relationships developed elsewhere so that they reflect specifically Idaho soils and subgrade conditions. The research conducted in this project is intended to provide the data necessary to more accurately quantify the seasonal and long-term variations in pavement and subgrade moisture, temperature, depth of frost and to relate these variations to subgrade soil types, pavement structures (layer materials and thicknesses) and local climate parameters, such as air temperature, precipitation, freezing index and thornthwaite moisture mix.



B: Climate Zones 1, 2, 4 and 5

Figure 1.1 Annual variations in subgrade resilient modulus (Ref 1.2)

1.2 Objectives

The overall objectives of the project are as follows:

1. Instrument pavements and subgrades to monitor moisture, temperature and frost/thaw depth variations over an extended period of time (at least five years).
2. Develop seasonal shift factors reflecting the seasonal and long-term variations in pavement layer and subgrade resilient Moduli for different regions (climate zones) within Idaho.
3. Examine the impact of seasonal variations in pavement support on WIM scales outputs and develop climate-based calibration factors for WIM measurements.
4. Examine the correlation of FWD deflection measurements and WIM scale signals to determine whether the WIM signals can be used to monitor deflections at WIM locations.
5. Evaluate and, if appropriate, adapt to Idaho conditions the recently developed FHWA Integrated Model of the Climatic Effects on Pavements (Integrated Model Program) (1.4). The FHWA integrated model contains three separate models of climatic effects on pavements: the Climatic-Materials-Structural Model (CMS) developed at the University of Illinois (1.5), the Infiltration and Drainage model (ID) developed at Texas A&M University (1.6) and the CRREL Frost Heave and Thaw Settlement Model developed by the U.S. Army Cold Regions Research and Engineering laboratory (1.7)

1.3 Specific Objectives of Phase 1

Due to the size and length of the project, it was decided by the project teams from the

University and the Idaho Transportation Department to conduct the proposed effort in phases. Phase One was designed to be essentially a planning and feasibility study with the following specific objectives:

1. Evaluate and select appropriate subgrade condition monitoring instrumentation.
2. Select the locations within the state at which pavements and subgrades would initially be instrumented, taking into account such factors as Strategic Highway Research Program (SHRP) seasonal sites, FWD data collection locations, weather station locations, subgrade soils, pavement structural layer materials and thicknesses, and construction schedules.
3. Develop the work plans and budgets for the extended study period.

Work performed to achieve the listed objectives is described in the following chapters.

CHAPTER TWO

INSTRUMENTATION

2.1 Introduction

The 1993 University of Idaho soil resilient modulus study (1.2) concluded that the major condition-related (environmental) factors causing changes in subgrade resilient modulus after construction are water content and temperature history. The main thrust of the research performed in Phase One was to evaluate and select instrumentation for long-term measurements of subgrade and pavement temperature, moisture and depth of freezing and thawing. The following discussion focuses on commercially available apparatus that has been used successfully in pavement research. Advantages and limitations of the available sensors as related in the literature reviewed (2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7) are briefly noted. Based on this review and in consideration of the scope and budget constraints of the proposed monitoring program, suitable sensors and readout equipment along with their costs as provided by the equipment manufacturers are identified.

2.2 Sensors and Measuring Equipment

2.2.1 Temperature Sensors

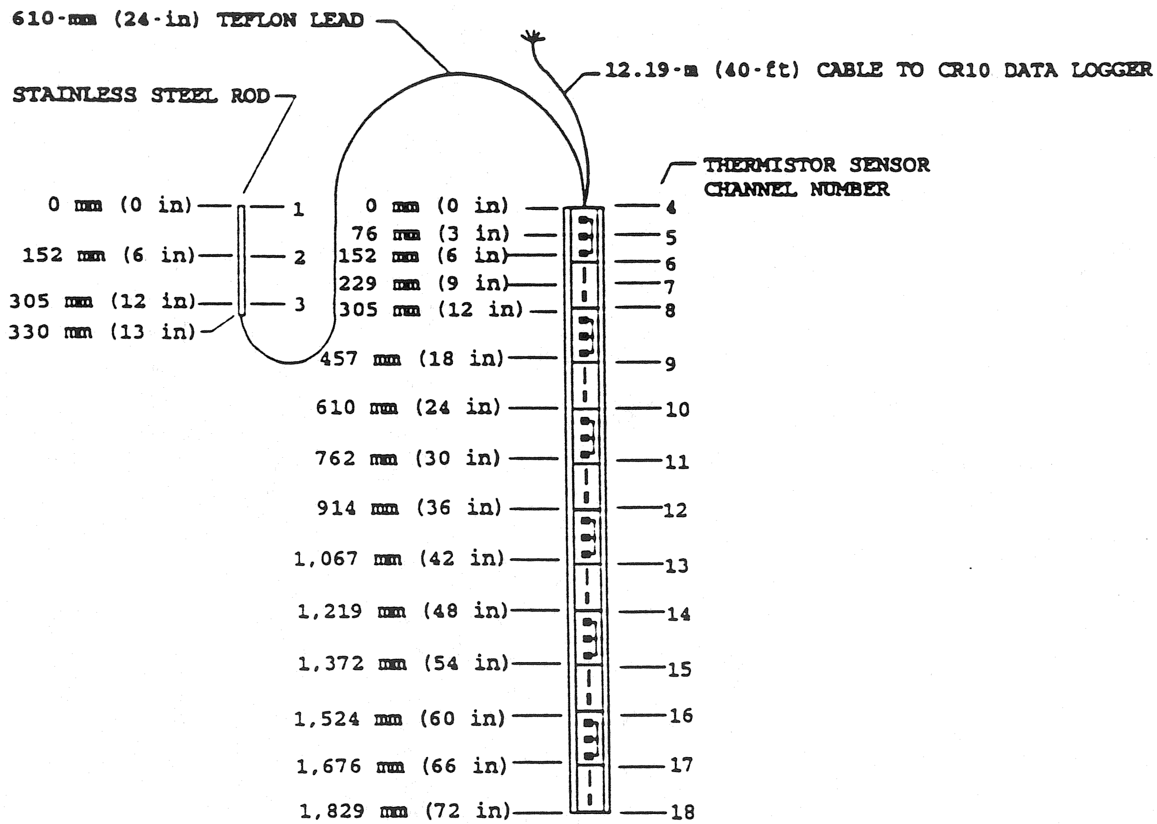
The most commonly used temperature sensors in pavement research are thermocouples and thermistors. <u>Thermocouples</u> consist of a junction of wires made of two dissimilar metals (e.g. copper-constantin) that produces a voltage which is proportional to the temperature of the junction. This voltage can be read with data loggers or small hand held "thermocouple readers", i.e., sensitive voltmeters. The voltage has to be compared to that produced by a thermocouple at a known "reference" temperature either directly, for example, by using ice bath, or analytically using a cubic equation developed by the National Bureau of Standards. Waterproofed thermocouple junctions can be embedded in or attached to a plastic rod (probe) for installation in the pavement, thereby providing a reasonably rugged, inexpensive array of temperature sensors.

Problems associated with thermocouples are the difficulty of obtaining good quality reference junctions and the extremely low voltages generated relative to background noise in the readout electronic circuits.

Thermistors are thermally sensitive resistors made from semiconductor material. Their large temperature coefficients of resistance can result in hundreds or thousands of ohms resistance change for even small changes in temperature. Changes in resistance are converted to temperature by using one of several nonlinear calibration equations. The appropriate equation (or curve) is usually provided by the manufacturers of the thermistors.

Multiple thermistors are available embedded in probes (plastic rods) with the leads and sensors permanently sealed. The sensor output can be read with data loggers or hand-held battery-powered digital multi-meters. A schematic of a thermistor probe is shown in Figure 2.1.

Problems associated with thermistors include errors introduced by self-heating of the resistors during measurements, "cable leakage" or a large decrease in the resistance between leads due to short circuiting by salty ground water and permanent biasing of the resistor due to the application of excessive current. The temperature coefficient of resistance of the thermistor materials may also change with the successive applications of the readout current so that the less often the devices are read, the longer they can be expected to last. Life expectancies of at least three or four years is usual, however, and up to six or eight years is not uncommon.



NOTES:

Dimensions:
Probe: 1,829 mm x 25 mm (72 in x 1 in) OD
External Sensors: 330 mm x 6 mm (13 in x 1/4 in) OD

Model TP101
Manufactured by Measurement Research Corporation
Total of 18 Thermistors
Degree of accuracy +/-0.1 degree C
External 330 mm (13 in) Lead attached by 610 mm (24 in) of Teflon Wire
76 mm (3 in) spacing from 0.0 mm (0 in) to 305 mm (12 in) and 152 mm (6 in) spacing from 305 mm (12 in) to 1,829 mm (72 in) and for the External Lead

Figure 2.1 Schematic of a thermistor probe (Ref. 2.6)

2.2.2 Moisture Sensors

Because of its importance in a wide range of soil behaviors, a large number of direct and indirect techniques for measuring soil water content have been developed. In this review only the methods capable of producing more or less continuous measurements of changing water contents made beneath an in-service pavement are considered. These restrictions limit the methods to electrical resistance blocks and the time domain reflectometry (TDR) technology.

<u>Electrical resistance blocks</u> indicate the moisture content (or matric potential) indirectly by measuring the electrical resistance between two electrodes embedded in a porous material in direct contact with the soil. The matric potential of the porous material (for example, gypsum) is assumed to be in equilibrium with the surrounding soil so that changes in resistance between the electrodes reflects changes in matric potential, and hence water content. Alternatively, the requirement for the relationship between soil matric potential (suction) and water content is frequently omitted and resistivity is simply empirically related to water content in the form of a nonlinear calibration curve.

Electrical resistance blocks have been widely used in the past, and because of their low cost, are still a viable alternative in some short-term applications. Their major limitations include the fact that the "soil resistance" is affected in major ways by other parameters including the mineralogy of the soil, and most notably, by the salinity of the soil water. Other problems have to do with their permanence. Because the electrodes must be in direct contact with the soil solution, they are extremely susceptible to corrosion. Extensive laboratory calibration effort is usually required. Resistances should be read with an alternating current voltage since direct current tends to polarize the electrodes. Hysteresis is also a problem and should be accounted for in the laboratory calibrations. There is no straight forward way to deal with long-term drift typically exhibited by resistance blocks.

Time Domain Reflectometry (TDR) has recently emerged as the technology of choice for both short-term and long-term "non-destructive" measurements of soil moisture. The technology ultimately is based on the development of the ability to measure and display very small changes in reflected electrical energy occurring during very short time periods. TDR was originally developed as a method for detecting faults (breaks) in communication cables. The time taken by an electrical pulse to travel along a cable to a discontinuity and be reflected back at the change in impedance at the discontinuity is measured. If the velocity of the pulse travel (wave velocity) along the cable is known, the distance to the discontinuity can be calculated. Thus, TDR is a type of radar system in which the energy pulse is confined to a two conductor cable. A discontinuity is any abrupt change in the dielectric constant of the material between or surrounding the two parallel conductors. The abrupt change in dielectric constant (and wave velocity) causes some of the energy to be reflected at points where the geometry and properties of the conductor change such as at a "probe", while the remaining energy (with its new velocity) continues on down the cable or probe. In probes designed to measure soils moisture content, a second energy reflection occurs at end of the probe. Since the probe length is known (fixed), the propagation velocity (which depends on the dielectric constant of the material surrounding the probe) can be computed as twice the probe length divided by the time required for the energy pulse to travel down the probe and back. The apparent dielectric constant of the surrounding porous medium is the ratio of this velocity and the speed of light, i.e. the velocity of the pulse in air. The apparent dielectric constant (permittivity) of air is one. Since the dielectric constant of dry soil varies from three to six and the dielectric constant of water is about 80, a moist soil's dielectric constant is essentially a function of its volumetric water content. The relationship between volumetric water content and apparent dielectric constant can be determined experimentally in the laboratory or reasonably accurate approximate measurements can be made using widely accepted empirical curves or calibrations provided by TDR probe manufacturers.

TDR probes designed specifically for measuring soil moisture are now available from several vendors in several conductor (probe) lengths and configurations. Individual probe elements are frequently configured as parallel conductors anywhere from 8 cm to 30 inches long which are placed or inserted in the soil with spacers used to maintain the conductors at a fixed distance apart, usually one to two inches. One end of each probe is connected to twinex cable (tv cable). The cable is led to the surface and connected to the readout instrumentation which consists essentially of a very sensitive oscillope or impulse (wave) timing device.

Individual parallel-conductor TDR probes can be placed in the soil in a horizontal configuration in preaugered and backfilled holes at any desired depth. An example of the horizontally oriented probes is shown in Figure 2.2.

Alternatively, probes are now available in preassembled long rods in which several pairs of conductors are oriented vertically (in series) with one connector exiting the top of the probes shown in Figure 2.3. The stainless steel-epoxy constructions can be pushed into loose and soft soils or they can be placed in predrilled holes and backfilled.

The advantages of the TDR technology are its durability, sensitivity, and the absence of a need to do extensive specific soil calibrations. Disadvantages include the costs (especially the readout equipment), the complicated calculations required for the basic units and the sensitivity of the response to salt concentration of the soil water. It's also necessary to establish the appropriate relationships between volumetric and gravimetric (weight-based) water contents for each soil unit weight of interest. For the vertically oriented probes, dielectric constants and

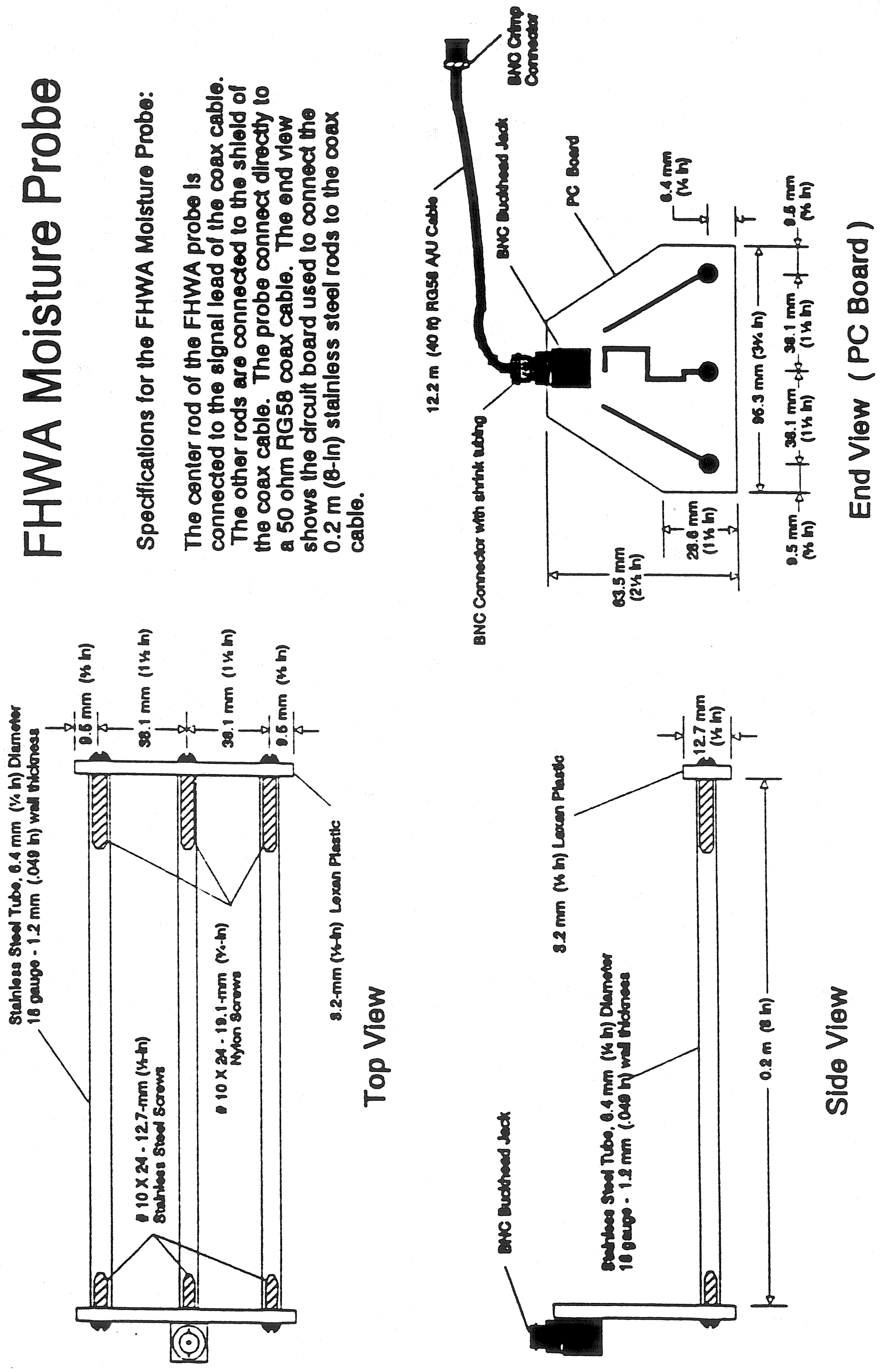


Figure 2.2 TDR probe developed by FHWA (Ref. 2.6)

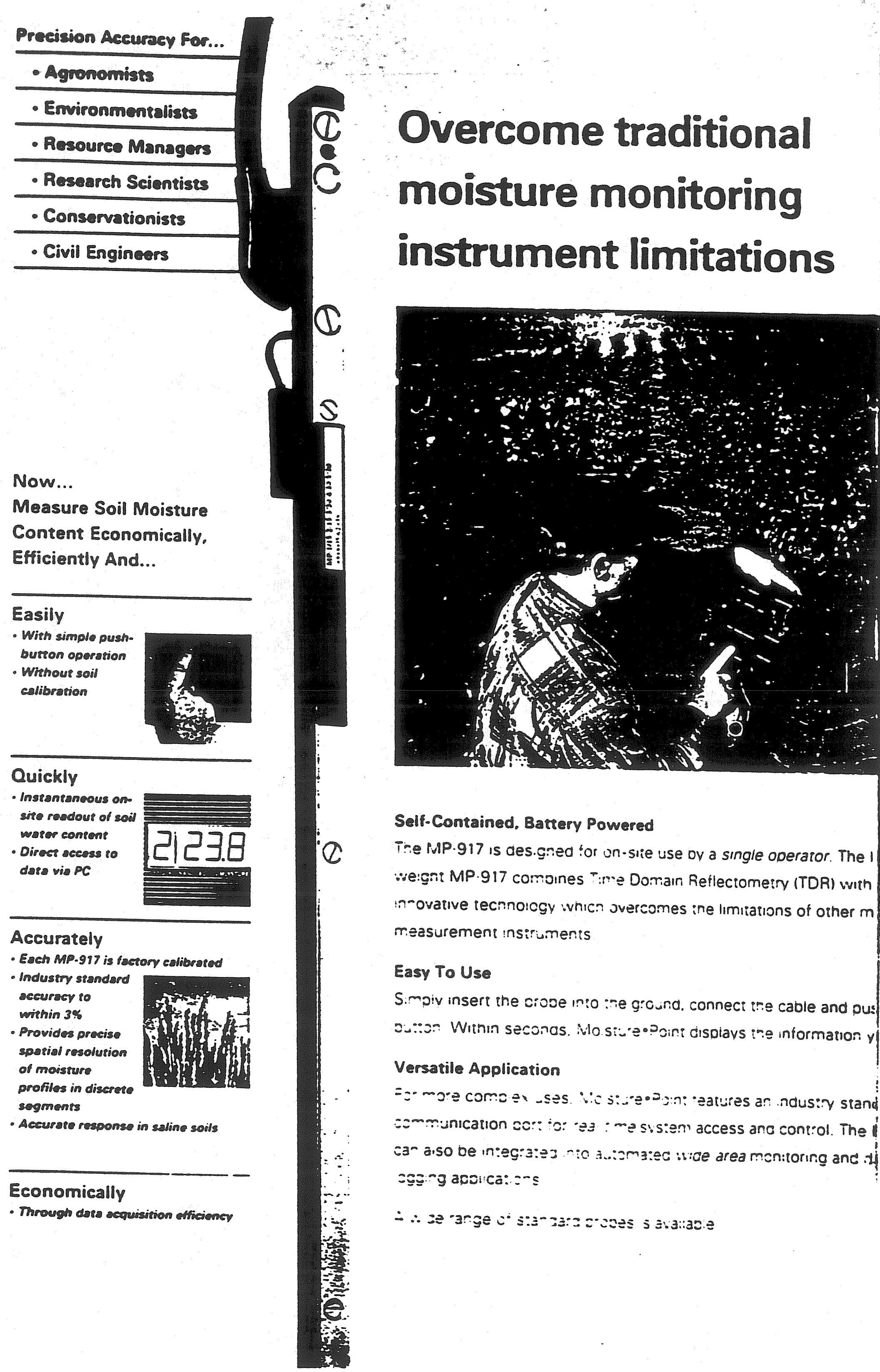


Figure 2.3 TDR probe developed by Gabel Corporation

subsequently calculated water contents represent conditions distributed vertically over the length of the individual probes in the string, which is typically about 30 cm.

2.2.3 Frost/Thaw Depth

Depth of freezing and thawing beneath pavements has been measured until recently using temperature sensors or frost tubes. The latter device consists of a clear plastic tube containing a colored dye which changes its shade when frozen. The clear tube is inserted into a second slightly larger vertical tube located in the pavement section and subgrade. Both the temperature sensor and frost tube approaches have severe limitations with respect to accurate frost depth measurements and have been replaced by the use of resistivity gages mounted along a cylindrical plastic probe.

Measurements of subgrade temperature are considered reasonable indicators of the depth of frozen soil during the first freezing cycle of the annual winter period, but upon subsequent thaws the approach is subject to substantial errors. During thaw cycles the temperature regime becomes isothermal from just beneath the surface (where air temperatures are above freezing) down to the maximum depth of the frost. This isothermal condition is an effect of the removal of the latent heat of fusion of the ice as it converts to water at the same temperature. The ice water conversion (melting) temperature is depressed an unknown amount due to the presence of soil minerals and dissolved salts. This, coupled with the fact that the sensors used to measure temperature typically have errors that exceed the expected uncertainty in the freezing point, makes it difficult to determine where the frozen soil boundary is with any precision or accuracy.

Frost tubes have the disadvantages that they have to be removed and read manually at the location where they're installed (often requiring that traffic be interrupted), and it is difficult to decide where the color shading change indicating freezing had occurred. The most serious limitation is that there was never close correlation between the freezing properties of soils and the tube/dye combination.

Frost resistivity probes appear to eliminate most of the problems associated with the two approaches referred to above. The probes utilize measurements of electrical resistivity made on copper electrodes mounted at small vertical spacings on a plastic cylinder buried in the soil profile: The probes can locate one or more boundaries between frozen and unfrozen soil to precision equal to the spacing of the pairs of electrodes (typically one to two inches). The determination is based on the wide difference between the resistivity of frozen soil (from 500,000 up to several million ohms) and thawed soil (20,000 to 50,000 ohms). The contrast is so large that the absolute values of resistivity are unimportant. A typical resistivity probe is shown in Figure 2.4.

Readout for the resistivity gages is made using alternating current in a wheatstone bridge circuit. The requirement for alternating current (necessary to prevent polarization of the electrodes due to reactions with dissolved salts in the soil water) complicates the design of a data logging system. Because frost depth is not a rapidly changing parameter, the need for manual measurements will not create problems in the proposed monitoring program.

2.2.4 Other Instrumentation

Observations of local air temperatures and, where appropriate, ground water levels will be made at the study locations. Air termperatures can be measured with an extra thermistor located in the junction box at the side of the pavement. The junction boxes will be all lockable metal boxes similar to those used with traffic signals. In locations where the ground water tables are

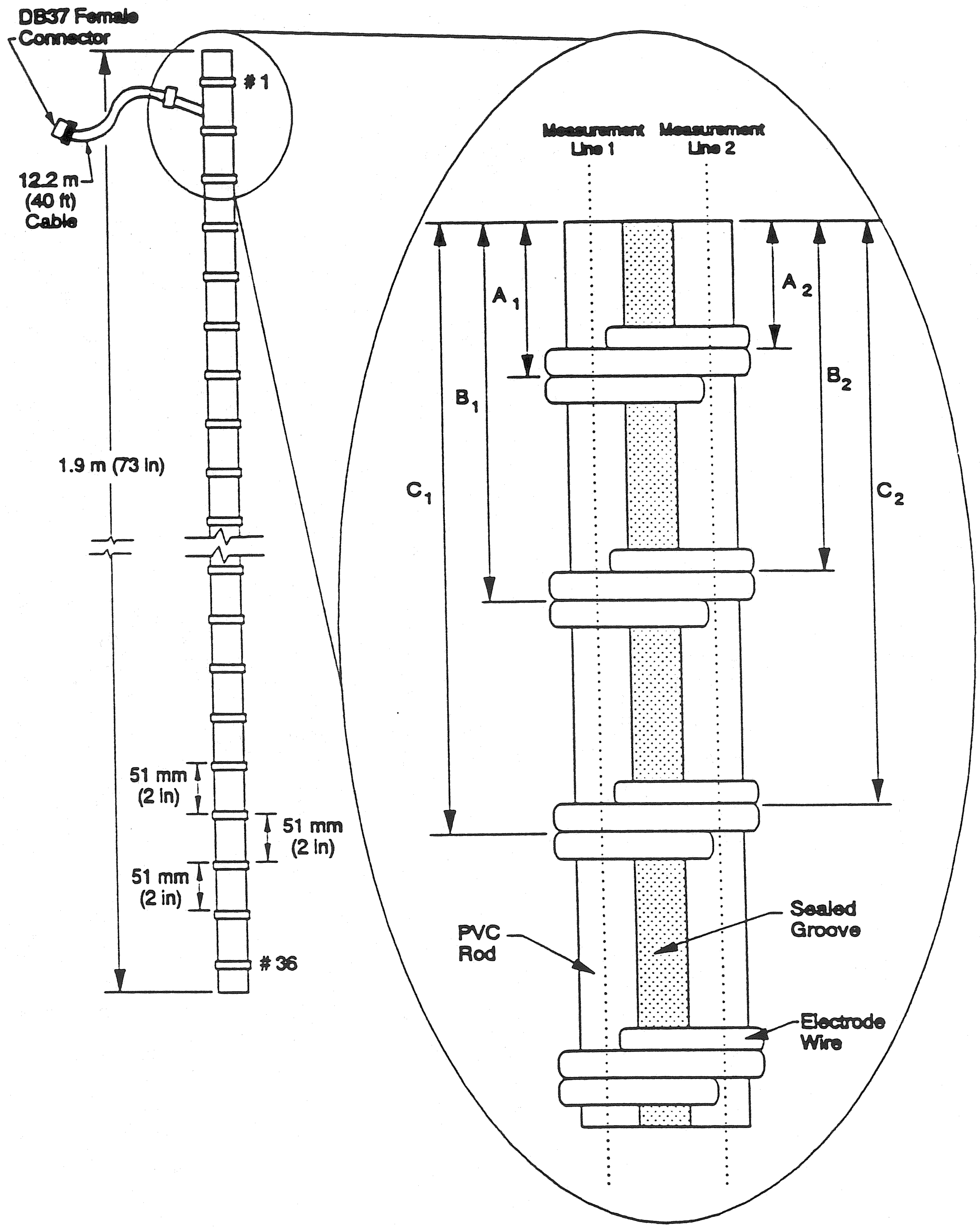


Figure 2.4 Resistivity probe developed by CRREL (Ref. 2.6)

within 30 ft. of the pavement level, open stand pipe piezometers with caps below the ground surface will be installed.

2.3 Instrumentation Costs

As noted above, a variety of instruments are available for measuring and recording the subgrade condition parameters of interest in this study. Costs associated with instruments and their indicating devices are generally proportional to their durability, accuracy, level of automation, and effort required for calibration. For purposes of comparison, two different instrumentation sets are described herein as List One and List Two. List One contains the instrumentation set selected for the project and its estimated costs. List two shows the instruments and costs for the absolutely lowest initial capital cost set. The items in List Two are believed to be substantially less durable and accurate than those in List One. Both lists are subdivided to show the costs of the instrumentation sets necessary for each pavement profile to be instrumented separately from the costs of the portable readout apparatus. Only a single set of the portable readout equipment is necessary to monitor all the instrumented sites that are within a reasonable distance (or region) of a central data storage location.

2.3.1 List One. Recommended Instrumentation

A. Instrumentation Required for Each Profile Site	Estimated Costs$
1. Subgrade Moisture: time domain reflectometry Suppliers: Gabel Corp. Soilmoisture Equipment Corp. Campbell Scientific, Inc.	800

2. Subgrade Temperature and Frost Depth: thermistor-resistivity probe Supplier: Measurement Research Corp.	2000
3. Ground Water Level: standpipe piezometer Supplier: In-house Manufacture	50
4. Air Temperature: air temperature probe Suppliers: Gable Corp. Soilmoisture Equip Campbell Scientific, Inc. Others	200
5. Miscellaneous Cables, Connectors, and Conduit	200
6. Junction Box (below ground)	50
Total Costs Per Site:	**$3300**

B. <u>Readout Instrumentation Required for Each Region</u>	Estimated Costs$
1. TDR Readout ("cable tester") Suppliers: Gabel Corp. Soilmoisture Equipment Corp. Tektronicx, Inc.	5500
2. Thermistor-Resistivity Readout Suppliers: Measurements Research Corp. Campbell Scientific, Inc.	1000
3. Battery Chargers	150
Totals Costs Per Region	**$6650**

2.3.2 List Two. Lowest Cost Instrumentation

A. Instrumentation Required at Each Profile	Estimated Cost $
1. Subgrade Moisture: soil moisture-temperature cells Supplier: ELE-Soiltest, Inc.	600
2. Subgrade Temperature: included in 1. above	
3. Frost Depth: resistivity probe Suppliers: ABF Manufacturing, Inc. Measurements Research Corp. Campbell Scientific, Inc.	900
4. Ground Water Level: standpipe piezometer	100
5. Air Temperature: hand held digital thermometer	100
6. Miscellaneous Cables, Connectors, and Conduit	100
7. Junction Box (below ground)	50
Total Costs Per Site	**$1850**

B. Readout Instrumentation Required for Each Region	Estimated Costs$
1. Moisture-Temperature Meter Supplier: ELE-Soiltest, Inc.	700
2. Digital Multimeter (resistivity probe readings) Supplier: Hewlett-Packard, etc.	500
3. Battery Chargers	150
Total Costs Per Region	**$1350**

Names and addresses of possible instrument manufacturers and vendors are contained in Appendix Two.

CHAPTER THREE

MONITORING SITES

3.1 Criteria for Site Selection

Several criteria were used in the evaluation of the research sites, including the following:

1. Recent or new construction was preferred .
2. Subgrades consisting of fine-grained soils or coarse soils containing significant amount of fines and possessing substantial capillary potential were preferred.
3. Pavements located at least 20 feet above the maximum groundwater table were preferred.
4. The opportunity to instrument similar pavements constructed on the same subgrade with one containing conventional dense-graded 3/4 inch minus aggregate base and the other containing the open-graded 2 ½ inch minus rock base ("rock cap") was a key criterion in the selection.
5. Proximity to operating weather stations was considered.
6. Proximity to SHRP and WIM sites was preferred.
7. Sites representative of differing climate regions within Idaho were preferred.

3.2 Selected Sites

During the course of the Phase One study, nine possible study sites were considered for instrumentation during the first year of the research. Following consultations with personnel from the Idaho Transportation Department (T. Buu, W. Capaul, J. Carpenter, K. Cole, K. Hahn, K. Nottingham, M. Santi, and R. Smith) and visits to the potential sites by the principal investigators, the following four sites were selected: (1) Wrenco-Dover, (2) US95 at Mica Flats, (3) SH8 at Moscow, and (4) SR128 in Lewiston. All the sites evaluated are listed in Table 3.1.

Table 3.1 Potential and Selected Study Sites

Identification	Location	Subgrade Origin
US95, Rock Creek	Bonners Ferry	Lacustine silts, sands
US95, Colburn-Pack R.	North of Sandpoint	Lacustine silts, clays
US2, Wrenco-Dover	West of Sandpoint	Lacustine silts, sands
US95, Mica Flats	South of Coeur d'Alene	Weathered sed. rocks, loess
SH8, Wash. St. Line to Line St.	Moscow	Alluvial and windblown silts
SR128, Downriver Road	Lewiston	Alluvial silts, sands
US95, Parma to County Line	Parma	Windblown and alluvial silts, sands
SR44N, Eagle Connector	Eagle	Weathered sed. rocks
I-84, Isaacs Canyon Int.	East of Boise	Windblown silts, sands

Instrumentation will be installed in 6-ft. deep holes drilled into the pavement sections as soon as possible after the construction is completed. The holes will be located in the outside wheel paths of the outside lanes in a manner similar to the SHRP recommendation shown in Figure 3.1 for the Long Term Pavement Performance Study (LTPP).

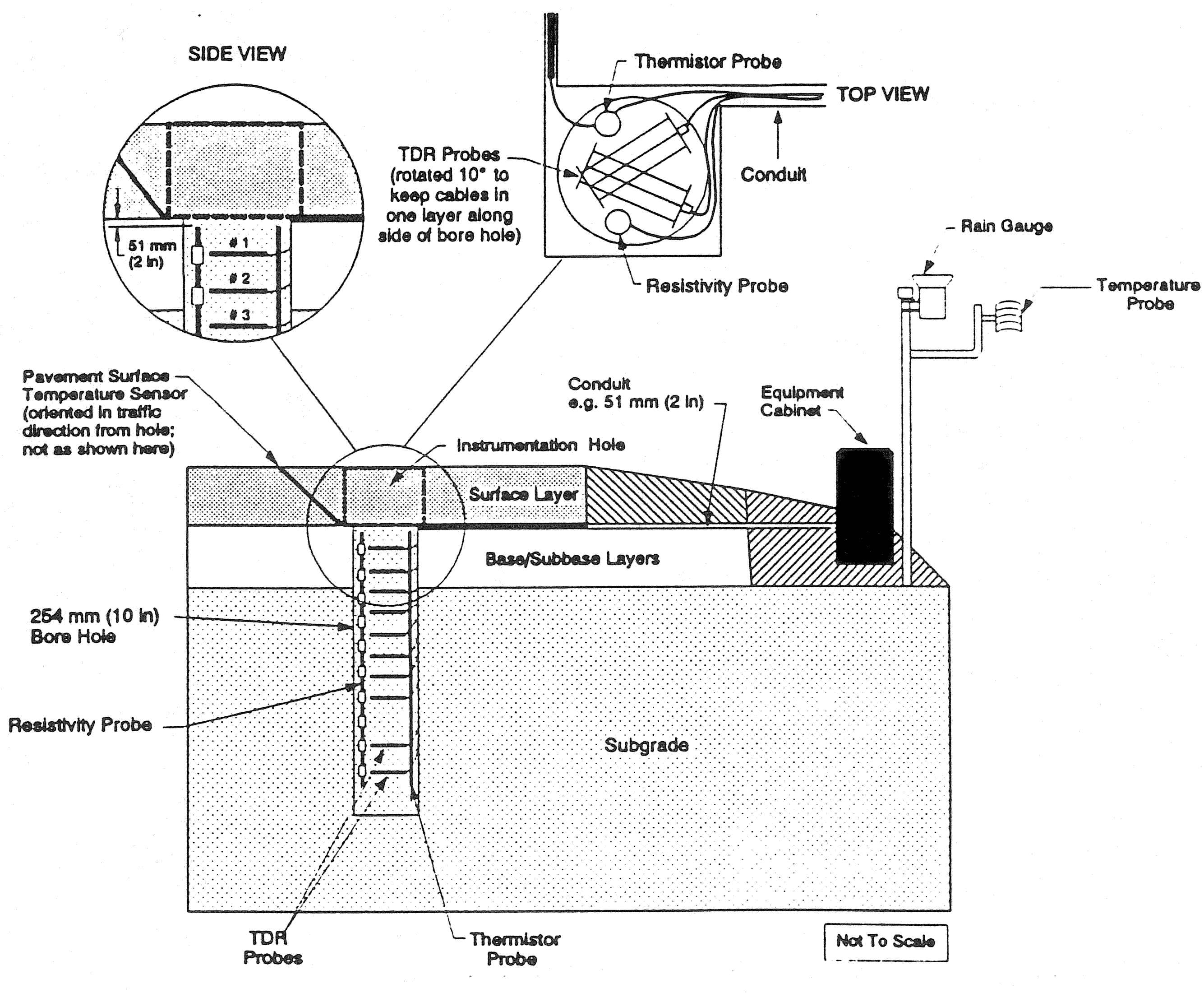


Figure 3.1 LTTP suggested instrumentation array (Ref. 2.6)

CHAPTER FOUR

PLAN OF RESEARCH

4.1 Plan for Phase 2: Field Instrumentation and Initial Data Collection

Phase 2 of this project is dedicated to instrument sites in Northern Idaho region with the jurisdiction of ITD Districts 1 and 2. Activities associated with this include equipment procurement, testing and calibration. Then, sensors would be installed and data collection would start at more frequently initially. Once data collection protocol is established, systematic periodical data collection will be performed.

Four pavements located in Districts 1 and 2 have been selected for instrumentation. The locations of the sites and their relationships to Idaho pavement climate zones are shown in Figure 4.1. In three of the locations, two profiles will be instrumented; one containing conventional dense graded base and one containing open graded rock cap. The fourth location, already constructed at Mica Flats, will be a profile that contains only the rock cap section.

Readings of subgrade and pavement conditions will be performed on a bi-weekly basis except at the SH8 location in Moscow, where readings will be taken weekly. Although air temperature and atmospheric moisture (precipitation) change rapidly, it is expected that the subgrade responses will be gradual and that the monitoring schedule selected will be sufficiently detailed. The weekly readings at Moscow will verify or disprove this assumption. Evaluation of the data will begin as soon as the first measurements are acquired. Data collected in Phase 2 will be analyzed to determine whether verification of climatic models, such as the FHWA integrated model (1.4) is possible and reasonable.

Additional work beyond the purchase calibration and installations of the instrumentation

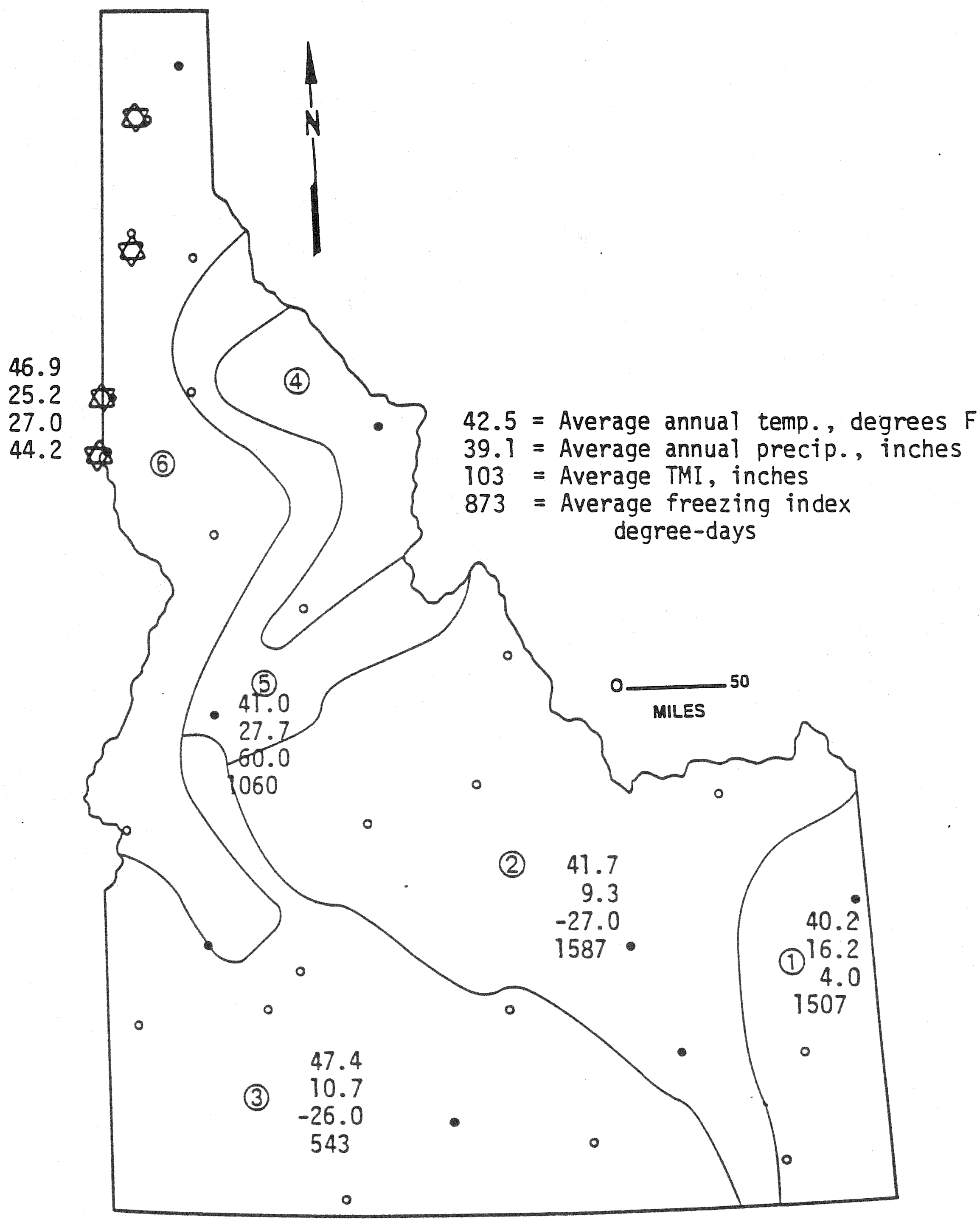


Figure 4.1 Initial study site locations and Idaho pavement climate zones (Ref. 1.2)

includes the completion of the laboratory testing program necessary to characterize and classify the subgrade soils and base materials from the four initial locations. Approximately 50 pounds of representative material will be required for the tests.

The tests to be performed are listed in Table 4.1.

Table 4.1 Subgrade and Base Classification Tests

Description	AASHTO Designation
Moisture-Density Relations of Soils	T99, T180
Specific Gravity of Solids	T100
Particle Size Distributions	T27, T88
Plasticity Limits	T89, T90
Moisture Characteristic Curves	T273
Resilient Modulus	T274

A tentative scope of research proposal for Phase 2 has been submitted to ITD. A copy of this proposal is included in Appendix Three.

4.2 Plan for Subsequent Phases

To satisfy the project overall objectives, pavement sites in other climate zones in the state of Idaho will be instrumented to develop the data needed for establishing seasonal shift factors for pavement layers Moduli. The new sites may include sites at WIM locations.

Subsequent phases may last two to four years after the completion of Phase 2. As the project progresses, changes to the data collection protocol may be necessary so that additional data may be acquired for models verification. Parallel to the data collection and analysis, more in-depth evaluation of the literature on climatic models will be conducted. The target is to establish and / or fine tune the an existing model that could be implementable in the State of Idaho. In addition, investigation of the data being collected for SHRP- LTPP program will be also looked at. The four years is needed to develop a statistically reasonable data base for model verification. After that, ITD may elect to continue data collection on regular basis.

The impact of this investigation on pavement design and rehabilitation procedures in the State of Idaho will be assessed. For instance, the overlay design program "FLEXOLAY" (4.1) and (4.2), newly developed at the University of Idaho, would be modified to reflect the seasonal shift factors established in this investigation.

An annual research plan will be developed to identify the activities to be performed in each year throughout the four year period.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

The previous sections of this report have described the instrumentation, costs, and locations for the initiation of a long term program of pavement and subgrade condition monitoring. The approach presented represents a minimum cost effort consistent with a reasonably high degree of apparatus durability and measurement accuracy.

The main activities in Phase 2 include procurement of equipment, testing and calibrating them and install them in selected sites. Four sites are selected in the Northern Idaho region for Phase 2 instrumentation. These sites are selected based on the established criteria as explained in Chapter 2. In three of these locations, open graded rock cap base material will be compared to conventional dense graded base. Data will be analyzed as they are acquired and a quarterly report will be prepared to include the results obtained.

For subsequent phases of the project (Long Term Plan), other sites will be instrumented in other climate zones in Idaho. These sites may include as well sites where WIM are located to investigate the seasonal effect on WIM measurements. Study of the literature on climatic models will be performed to evaluate their applicability to Idaho.

APPENDIX ONE

REFERENCES

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APPENDIX TWO

INSTRUMENT VENDORS

A.1 Temperature (Thermistor Probe)

1.1 MRC Measurement Research Corporation

4126 4th Street, NW

Gig Harbor, WA 98335

Phone: (206) 851-3200

Contact: Pat Martka

1.2 Campbell Scientific, Inc.

815 West 1800 North

Logan, UT 84321

Phone: (801) 752-7779

Contact: Don Anderson

1.3 ELE-Soiltest, Inc.

P.O. Box 8004

Lake Bluff, IL 60044-8004

Phone: (800) 323-1242

A.2 Frost/Thaw Depth (Resistivity Probe)

2.1 MRC Measurement Research Corporation

2.2 ABF Manufacturing, Inc.

13060 43rd Street, NE

St. Michael, MN 55376

Phone: (612) 497-4507

Contact: Arthur Finkelstein

2.3 ELE-Soiltest, Inc.

A.3 Soil Moisture (Time Domain Reflectometry and Moisture Blocks)

3.1 Campbell Scientific, Inc.

3.2 Soil Moisture Equipment Corporation

P. O. Box 30025

Santa Barbara, CA 93105

Phone: (805) 964-3525

Contact: Herb Fancher

3.3 Gabel Corporation

13240 Evening Creek Drive-South, Suite 316

San Diego, CA 92128

Phone: (619) 486-5688

Contact: John Johnston

3.4 ELE-Soiltest, Inc.

APPENDIX THREE

Proposal for Phase 2 Scope of Work

COOPERATIVE TRANSPORTATION RESEARCH PROGRAM (U of I and ITD)

PROJECT TITLE

Monitoring and Modeling Subgrade Soil Moisture for Pavement Design and Maintenance in Idaho. Phase 2: Site Instrumentation and Initial Data Collection

BACKGROUND

Recent projects conducted in the Civil Engineering Department with regard to pavement design systems identified the need for measuring seasonal moisture, temperature and frost variation and predicting the associated variation of the modulus of resilience of subgrade soils as well as for other pavement layers. The assessment of these environmental variation of pavement materials and subgrade soils is instrumental in developing a mechanistic design system. This research project is planned to satisfy these needs. In the first phase of this project an investigation was conducted to select cost effective and durable instrumentations suitable for measuring these variables (moisture and temperature). The study has revealed that the most effective approach is to use TDR based instrumentation. Phase 2 of the project is dedicated to instrument sites in the northern region of the state and establish the data collection protocol which may be duplicated at other location in the various climatic zones.

Objectives:

As was stated in Phase 1, the overall objectives of this project are to:

- Instrument pavements to monitor moisture and temperature variation in subgrade soils and pavement layers. Monitoring is to be conducted over a long period of time, at least three years.
- Develop seasonal shift factors that reflect the variation of pavement layer moduli with seasonal variation of moisture, temperature and frost for different regions in Idaho.
- Examine the impact of seasonal variations in pavement support on WIM scales output. Develop a climatic based calibration factors for WIM measurements.
- Examine the correlation of FWD deflection measurements and WIM scale signals and determine whether these signals can be used to monitor deflections at WIM locations.
- Evaluate the recently developed FHWA Integrated Climatic Model methodology for applicability to conditions in Idaho.

The specific objective of Phase 2 is to instrument selected sites and start data collection.

Phase 2 Activities:

The activities that will be performed during this phase are:

1. Procurement, testing and calibration of instrumentation.
2. Basic soil testing for classification purposes and to determine soil suction properties.
3. Instrumentation of selected sites.
4. Moisture and temperature data collection (pilot study) to identify possible problems and

refine data collection scheme.

The selected sites for north region are:

- State Highway 8 form Washington State borders to Line street. Two sites adjacent to each other. One with rock cap and the other with aggregate base (Loess soils).
- State Highway 128 (Down River Road), Lewiston (new fill). Two sites rock cap and aggregate base)
- Mica Hill on US 95 (SHRP Site) about 5 miles south of Coeur d'Alene (Latah formation).
- US 2 Wrenco to Dover, six miles west of Sand Point (Lacnstrine sands).

Data Collection:

Once the sites are instrumented, we will start collecting data more frequently, about once a week initially. If it proved that longer period is needed to observe changes, data collection schedule will be changed accordingly. A report on the findings will be prepared by the end of the project.

Cooperative Effort:

University Team: Dr. Fouad Bayomy and Dr. James Hardcastle
Transportation Dept. Team: Mr. Robert Smith, Mr. Ken Hahn and Dr. Kerby Cole

UI TEAM The UI team are responsible of procurement of instrumentation, testing and calibrating them. They will also conduct the basic soil testing and establish the soil suction curves. Agriculture laboratories will be used for some of these tests. Dr. Bayomy will act as the principal investigator and will be responsible for deliveries to ITD including report submittal and budget monitoring. He will be responsible of the coordination of all project activities.

ITD Team: The assistance needed from ITD is in the installation of the sensors. ITD will provide and operate a drilling unit to drill holes in the pavement at selected sites. This activity could be done directly by a ITD crew or by subcontracting. In such case, additional funds will be needed for the drilling cost.